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The Feasibility of Solar Reflector Production From  
Lunar Materials for Solar Power in Space  
SAIC Corporation, San Diego

Summary

Science Applications International Corporation (SAIC) has investigated the feasibility of producing solar reflectors from indigenous lunar materials for solar power production on the Moon. First, lunar construction materials and production processes were reviewed, and candidate materials for reflector production were identified. At the same time, lunar environmental conditions were reviewed for their effect on production of concentrators. Next, conceptual designs and fabrication methods were proposed and studied for production of dish concentrators and heliostats. Finally, fabrication testing was performed on small-scale models using Earth analogues of lunar materials. Findings from this initial investigation indicate that production of concentrators from lunar materials may be an attractive approach for solar energy production on the Moon. Further design and testing are required to determine the best techniques and approaches to optimize this concept.

Four materials were identified as having high potential for solar reflector manufacture. These baseline materials were foamed glass, concrete with glass-fiber reinforcement, a glass-fiber/glass-melt composite, and an iron-glass sintered material. Lunar-produced metals were generally expected to be too costly and their production too energy intensive for large-scale use in solar reflector fabrication. Two exceptions to this conclusion are the use of very thin foils for heliostat membranes (like terrestrial membrane heliostats) and the use of aluminum for reflective surfaces. Vacuum-sputtering of aluminum onto the front surface of concentrators was selected as the best approach for production of all reflective surfaces.

Molding of dish reflectors on male molds was chosen as the preferred method of fabrication over free-forming techniques using membrane technology or spin molding. The main advantage of molding is reduced risk. Techniques for focusing heliostat concentrators using static electricity were identified. A passive tracker drive for dish concentrators was also proposed.

Testing of fabrication techniques is being carried out for the four baseline materials. Small-scale models of lunar dishes are being fabricated. The foam glass material is being simulated by polyester resin containing glass microspheres. This allows testing to be conducted at room temperature. Lunar concrete is being simulated with high-alumina cement and ground terrestrial anorthite aggregate, and chopped glass fibers are being used for reinforcement. Fabrication tests with the glass-glass composite and iron-glass sintered material are being conducting using high-lead glass,

with a low melting temperature for the molten glass portion, in order to reduce temperature requirements for the tests.

### Introduction

Dependence upon the Earth for materials and power makes a space colony very vulnerable to supply problems. Also, the cost of transport of materials out of the Earth's gravitational potential well is very high. Finally, the most available form of long-term power is solar energy. Therefore, production of a solar collection system in which large portions of the system are constructed of indigenous materials has promise for increasing the autonomy and security of such colonies. Lunar colonies are of particular interest at present, due to the Moon's proximity and its likelihood as a starting point for colonization and as a debarkation point for extended excursions into space.

In this project, Science Applications International Corporation (SAIC) has studied the feasibility of using materials produced from lunar soil to form reflectors for distributed or central concentrating solar power systems for lunar settlements. These systems may employ photovoltaic or solar thermal receivers to produce electric power or provide high-temperature thermal energy for the needs of the lunar colony.

### Lunar Materials Evaluation

The lunar surface is unique in comparison to terrestrial soils. One effect of meteorite impacts is to mix and homogenize surface constituents through great depths of soil. This fact, together with the lack of a hydraulic cycle on the Moon, means that no ore deposits or mineral concentrations due to evaporation are to be found. Another effect of meteorite impacts is the lithification of various components of the soil into lunar rocks called breccias. Thermal cycling and micrometeorite impacts contribute to the comminution of surface materials into a very fine dust, which forms the "lunar soil," or regolith. The lack of life-forms eliminates the presence of organic compounds, and many common terrestrial constituents such as C, Na, and Cl are also rare. Finally, the lunar surface environment, consisting of a high vacuum, means that the only gases present in the surface materials are those captured from the solar wind.

The lunar surface may be broadly divided into mare and highland regions. Mare regions are characterized by being low-lying areas consisting mainly of basalts that were ejected from the Moon's core. The highlands are, physically, about a kilometer above the maria and consist mainly of feldspar-rich plutonic material, with minor amounts of aluminum and trace-element-rich basaltic minerals. Table 2.1 (taken from

Table 2.1 Chemical compositions (Wt. %) for the major minerals.

## a. High-Titanium Basalts

	Modal Abundance (Volume %)			
	Pyroxene 42-60%	Olivine 0-10%	Plagioclase 15-33%	Opakes (Mostly Ilmenite) 10-34%
Al <sub>2</sub> O <sub>3</sub>	0.6- 6.0	--	28.9- 34.5	0.0- 2.0
TiO <sub>2</sub>	0.7- 6.0	--	--	52.1- 74.0
Cr <sub>2</sub> O <sub>3</sub>	0.0- 0.7	0.1- 0.2	--	0.4- 2.2
FeO	8.1- 45.8	25.4- 28.8	0.3- 1.4	14.9- 45.7
MnO	0.0- 0.7	0.2- 0.3	--	<1.0
MgO	1.7- 22.8	33.5- 36.5	0.0- 0.3	0.7- 8.6
CaO	3.7- 20.7	0.2- 0.3	14.3- 18.6	<1.0
Na <sub>2</sub> O	0.0- 0.2	--	0.7- 2.7	--
K <sub>2</sub> O	--	--	0.0- 0.4	--

## b. Low-Titanium Basalts

	Modal Abundance (Volume %)			
	Pyroxene 42-60%	Olivine 0-36%	Plagioclase 17-33%	Opakes (Mostly Ilmenite) 1-11%
SiO <sub>2</sub>	41.2- 54.0	33.5- 38.1	44.4- 48.2	<1.0
Al <sub>2</sub> O <sub>3</sub>	0.6- 11.9	--	32.0- 35.2	0.1- 1.2
TiO <sub>2</sub>	0.2- 3.0	--	--	50.7- 53.9
Cr <sub>2</sub> O <sub>3</sub>	0.0- 1.5	0.3- 0.7	--	0.2- 0.8
FeO	13.1- 45.5	21.2- 47.2	0.4- 2.6	44.1- 46.8
MnO	0.0- 0.6	0.1- 0.4	--	0.3- 0.5
MgO	0.3- 26.3	18.5- 39.2	0.1- 1.2	0.1- 2.3
CaO	2.0- 16.9	0.0- 0.3	16.9- 19.2	<1.0
Na <sub>2</sub> O	0.0- 0.1	--	0.4- 1.3	--
K <sub>2</sub> O	--	--	0.0- 0.3	--

## c. Highlands Rocks

	Modal Abundance (Volume %)			
	Pyroxene 5-35%	Olivine 0-35%	Plagioclase 45-95%	Opakes (Mostly Ilmenite) 0-5%
SiO <sub>2</sub>	51.1- 55.4	37.7- 39.9	44.0- 48.0	0.0- 0.1
Al <sub>2</sub> O <sub>3</sub>	1.0- 2.5	0.0- 0.1	32.0- 36.0	0.8- 65.0
TiO <sub>2</sub>	0.45- 1.3	0.0- 0.1	0.02- 0.03	0.4- 53.0
Cr <sub>2</sub> O <sub>3</sub>	0.3- 0.7	0.0- 0.1	0.0- 0.02	0.4- 4.0
FeO	8.2- 24.0	13.4- 27.3	0.18- 0.34	11.6- 36.0
MgO	16.7- 30.9	33.4- 45.5	0.0- 0.18	7.7- 20.0
CaO	1.9- 16.7	0.2- 0.3	19.0- 20.0	0.0- 0.6
Na <sub>2</sub> O	--	--	0.2- 0.6	--
K <sub>2</sub> O	--	--	0.03- 0.15	--

Waldron et al. 1979) summarizes the ranges of chemical compositions for the major minerals that are found in these regions.

The metal-bearing silicates, pyroxene, anorthite, and olivine are the primary minerals available from the lunar surface. The oxide ilmenite is also present to a lesser extent. These mineral groups contain oxygen, silica, and the metals iron, magnesium, titanium, and aluminum. The lunar regolith also contains a high concentration of glass from micrometeorite bombardment. To exploit these natural resources, the raw material must be heated to allow certain chemical reactions to occur. The amount of thermal energy required to process these minerals depends largely on the specific heats and melting points of the minerals. These data are shown in Table 2.2 (taken from SAIC 1989).

Table 2.2 Thermal properties of various lunar materials.

Mineral	$C_p$ (kJ/kg/K)	$C_p$ (kWh/kg/K)	Melting Point ( $^{\circ}$ K) <sup>a</sup>
Ilmenite ( $\text{FeTiO}_3$ )	0.687	0.000190	1640
Anorthite ( $\text{CaAl}_2\text{Si}_2\text{O}_8$ )	0.755	0.000209	1823
Olivine [ $(\text{Mg}_2, \text{Fe}_2)\text{SiO}_4$ ]	0.790	0.000219	1478-2163
Pyroxene [ $(\text{Mg}, \text{CA}, \text{Fe})\text{SiO}_3$ ]	0.766	0.000213	1813-1830

<sup>a</sup>From Williams and Jadwick (1980).

Many useful products can be generated from lunar minerals via various chemical and physical processes. Some of the processes being considered are hydrogen reduction, carbothermal reduction, carbochlorination, hydrofluoric acid leaching, magma electrolysis, and vapor phase reduction. These processes extract oxygen, metals, and silicates from the lunar regolith. For the purposes of this study, the materials of particular interest are structural materials for solar reflector support structures and surfaces and materials that can be used for coatings (particularly aluminum for reflective surfaces). Table 2.3 shows that high-strength metals, glasses, ceramic materials, and concrete-like materials form the basic possibilities for lunar structural materials. The production, abundance, and characteristics of each of these types of materials are discussed in the following subsections.

*Metals.* Metals found on the Moon in significant quantities include iron, aluminum, magnesium, and titanium. Processes to extract these elements from lunar soil have been

Table 2.3 Possible useful products from lunar sources.

**Structural Materials**

Metals: Steels, aluminum, magnesium, titanium  
 Reinforced Metals: Aluminum, magnesium reinforced with silica, steel, or alumina  
 Glasses, fused silica  
 Ceramics, alumina, magnesia, silica, compounds  
 Hydraulic cements (need water)

**Thermal Materials**

Refractories plus chromia, titania, titanium silicide  
 Same as ceramics above, plus castables, ramming cements, insulation, fiberglass, fibrous or powdered ceramics

**Electrical Materials**

Conductors: Aluminum, iron, resistance alloys (FeCrAl)  
 Electrodes: Graphite,  $\text{Fe}_3\text{O}_4$   
 Magnetic materials, iron alloys, magnetic ceramics  
 Insulation, glass, ceramics

**Fibrous Materials**

Glass, silica (for apparel, paper, filters, etc.)

**Plastics, Elastomers, and Sealants**

Soluble silicates, silicone resins (contain some C)

**Adhesives and Coatings**

Anodized aluminum, magnesium, titanium electroplating (Cr)  
 Sputtered coatings, etc.

**Lubricants, Heat-Transfer Fluids**

Sulfides,  $\text{SO}_2$ , He

**Industrial Chemicals**

Detergents, cleansers, solvents, acids, bases,  $\text{H}_2\text{SO}_4$ ,  $\text{H}_3\text{PO}_4$ , CaO, NaOH

**Biosupport**

Oxygen (breathing), 16/18 of water by mass  
 $\text{SiO}_2$ : Soil component (includes many trace nutrients)  
 Constituent Elements of Life-Forms: O, Ca, C, Fe, Mg, K, P, N, Na, H, and others

developed (Waldron et al. 1979, AIAA 1988) and their use as structural elements needs no explanation. However, there are constraints in both their absolute quantities in lunar soils and in other materials needed to utilize these materials effectively. For instance, some important alloying materials for the production of steel, such as C, Ni, Mo, W, V, and Nb, are not readily available on the Moon. Likewise, production of high-strength alloys of aluminum, magnesium, and titanium require elements (particularly Zn and Mo) not found in abundance on the Moon. Thus, although many commercial alloys can be

made solely from lunar materials, importation of small amounts of some materials from Earth is almost certain.

Metals are not found in large concentrations in lunar materials, although elemental iron is found in the form of small particles in some lunar materials. In any case, significant processing must be done to obtain useful structural alloys. Therefore, in comparison to some of the other structural materials available, such as glass, it may require more effort to produce the large quantities of metallic materials needed for large solar reflectors from lunar materials. Also, metallic materials have many uses for which other materials cannot easily be substituted, such as electrical conductors. Thus, their use may be, to a large extent, dictated by other needs of the lunar colony. For these reasons, metals are expected to be less attractive than other lunar materials for use in solar reflectors. One probable use for metals in solar reflectors is vacuum-deposited aluminum to produce highly reflective surfaces. This is expected to be attractive because the process uses very little material, it requires a vacuum environment anyway, and it produces high-quality reflective surfaces.

*Glasses.* All lunar materials form glasses easily upon being melted. In fact, the presence of small glass spheres is common in lunar samples (although they constitute only a tiny percentage of the total mass) due to vitrification from meteorite impacts. Lunar mare materials consist of a material very similar to terrestrial basalt. Here on Earth, cast basalt is already used for chemical process components, including pipes, tees, Y-sections, and cyclones. Thus, the technology for processing this material is already developed. Although normal lunar glass is brown due to impurities, glass produced from anorthite can be made colorless by the removal of iron contamination.

In earlier studies (NASA n.d., Lunar and Planetary Institute 1980), glass from lunar materials was proposed as the structural material from which most of a space power system could be constructed. The proposed process, shown in Figure 2.1 (from Lunar and Planetary Institute 1980), takes normal lunar soil, removes metallic iron particles magnetically, and then melts the remainder to form a glass melt from which fiberglass and glass sheet are produced. In addition, it was proposed to electrolyze oxygen from the melt for the production of foamed glass. Other studies performed at Los Alamos National Laboratory proposed that lunar soil could be melted in-place by an electrically heated molybdenum or tungsten mandrill to form a glass-like material that would form the walls and ceilings of a lunar habitat (Rowley and Neudecker 1980).

Another factor in favor of the use of glass over metals is the amount of energy required to produce it. Table 2.4 (from Friedlander and Cole 1989) summarizes the energy and power requirements for lunar glass and metals processing. Glass products

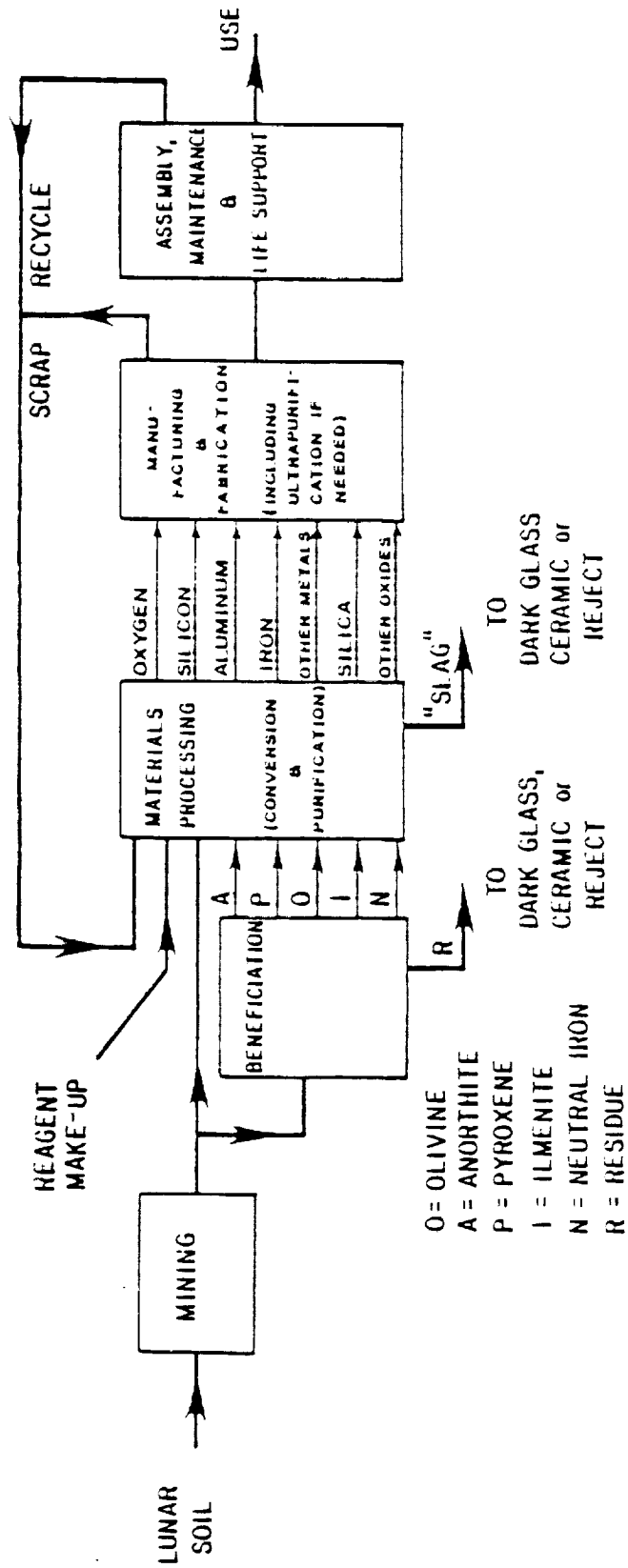


Figure 2.1 Schematic process for production of lunar glass products.

Table 2.4 Energy and power requirements for lunar glass and metal production.

	Product				
	Fiberglass	SilicaGlass	Aluminum	Titanium/Iron	Iron
Beneficiated Feedstock	Anorthite	Bulk soil slag, CoO	Anorthite	Ilmenite	Ilmenite
Process Technique	Meltdown	Meltdown	-----Carbochlorination-----		Carbothermal
Process Energy (kWh/ton)					
Thermal	878	534	9890	2080/4910	3500
Electric			9000		
Throughput (tons/yr)	10,000	10,000	1000	860/1000	1000
Total Power (kW)					
Thermal	1000	610	1129	765	400
Electrical	55	17	1049	25	41

require far less energy to produce than any of the metals listed. In addition, they are amenable to far larger production volumes.

Since glass can be easily produced from lunar materials in large quantities, it appears a very promising material for solar reflectors. Glass has many desirable characteristics for production of solar reflectors, including high strength, low chemical activity, excellent surface finish, and ease of forming. Clear glasses could also have applications as lenses or cover glasses for optical components.

*Ceramic Materials.* Along with components that form glasses, lunar materials contain a high fraction of ceramic materials and ceramic pre-cursors. In particular, alumina ( $\text{Al}_2\text{O}_3$ ), silica ( $\text{SiO}_2$ ), and magnesia are all present, or can be produced in significant quantities. It is possible to produce a glass-ceramic product from lunar materials that has a tensile strength greater than 345 MPa (50,000 psi) (MacKenzie and Claridge 1979). Ceramics may be useful in the production of glass (e.g., melt tanks can be made of silica), and they can be used as refractory components of solar collectors (e.g., thermal receivers). Finally, pure silicon produced from lunar materials can be used to make photovoltaic cells.

*Cementitious Materials.* Little consideration has been given to cement-like lunar materials until very recently, when the Construction Technology Laboratory (CTL) associated with the Portland Cement Institute began to study the production and use of concrete from lunar materials (Lin 1987a, 1987b). These studies have shown that lunar soils can serve as aggregate and that the residue from a simple high-temperature

evaporation process performed on lunar basalt materials may serve as a high-alumina cement. A small block of concrete was, in fact, produced by CTL using Apollo 16 lunar sample materials as aggregate. This concrete sample was tested at CTL to determine its properties, which are summarized in Table 2.5.

Table 2.5 Physical properties of concrete with lunar aggregate.

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Compressive Strength:	75.7 MPa
Modulus of Rupture:	8.3 MPa
Modulus of Elasticity:	21,400 MPa
Thermal Expansion Coefficient:	$5.4 \times 10^{-6}$ cm/cm/°C

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Normal concrete has a low flexural strength (about 10% of its compressive strength). Reinforcement of lunar concrete with glass or steel fibers can greatly increase its flexural strength, strain energy capacity, and ductility. For instance, reinforcement with 4% steel fibers by weight nearly doubles the flexural strength. Both glass and steel can be produced from lunar materials for use as fiber reinforcements.

Lunar concrete has many good characteristics as a construction material. Concrete strength is retained at temperatures as low as -150°C; in fact, its strength actually increases at low temperatures if the humidity is high. Similarly, strength is nearly constant to temperatures of 250°C or more, and concrete is thermally stable to 600°C or more. Another useful characteristic of concrete is its high resistance to abrasion, which protects against micrometeorite damage. Finally, concrete is resistant to radiation damage and is stable in a vacuum environment.

One possible complication in the use of lunar concrete is that water is required for the formation of concrete (about 4% by mass). Since water is essentially non-existent on the Moon, it would probably need to be imported from Earth. The impact of this can be reduced by shipping only hydrogen, which saves 16/18 in the mass that needs to be transported. The hydrogen would be combined with oxygen produced from the lunar soil to form the needed water. Using this approach, the material that would need to be transported from Earth is 0.4% of the final concrete mass.

#### Lunar Conditions and Constraints

In considering the production of solar reflectors on the Moon, consideration of the characteristics of the lunar environment is essential. The lunar environment affects the design, the fabrication, and the operation of any solar reflectors that are produced.

Salient characteristics of the lunar environment are listed in Table 2.6. These include both atmospheric and geologic factors.

Table 2.6 Characteristics of the lunar environment.

<b>Atmosphere</b>	
Pressure:	<10 <sup>-14</sup> torr
Surface Temperatures:	Daytime up to 110°C Night down to -170°C
Solar Insolation:	1350 W/m <sup>2</sup> ± 3% due to orbital eccentricity
Solar Wind:	Charged particles of H, O, and other species
Length of Lunar Day:	708 hours
Inclination of Axis to Ecliptic:	1/2°
<b>Geology</b>	
Gravitational Constant:	1.62 m/s <sup>2</sup> + perturbations in maria
Magnetic Field:	<4.4 × 10 <sup>9</sup> tesla/cm <sup>3</sup>
Moonquakes--Frequency:	Several thousand per year
Energy Release:	<3.6 × 10 <sup>5</sup> MW
Average Severity:	< 2 on Richter Scale
Maximum Severity:	4 on Richter Scale
Surface Heat Flux:	0.02 W/m <sup>2</sup>

In the present study, the most important characteristics related to the production and operation of solar reflectors are micrometeorite impacts, temperature variations, gravity, and atmospheric pressure on the lunar surface. Of secondary importance are the solar wind components and the effects of moonquakes. Finally, magnetic field and heat flux effects are expected to be negligible.

#### Summary of Lunar Concentrator Meeting of 21 November

*Materials.* Several additional potential structural materials were identified in the course of the meeting:

- Relatively low-temperature (1000°C) sintering of iron-enriched (i.e., magnetically separated) lunar soil to produce a structural material. This would be a simpler process than either glass or concrete production from lunar soil.
- Use of foamed glass in the same way as concrete to form structural shapes. This would have the additional advantage that the front surface could be made to form a smooth skin for application of the reflective coating. Also, compared to a thin sheet of glass, a foam would be more resistant to fracturing from micrometeorite impacts.

- A glass-glass composite consisting of high-temperature glass fibers in a low-temperature glass "cement" matrix. This would give a composite with good tensile, as well as compressive, strength for dishes, etc.
- Lamination of glass layers to achieve improved strength.

Vacuum-deposited aluminum as a reflective surface was adopted as a baseline. Because of the difficulty in obtaining an optically smooth surface on concrete, it will require a surface coat of glass or some other substance. This adds another step to the fabrication process.

One possible disadvantage identified for glass collectors is their susceptibility to fracture once cracked (for instance, by micrometeorite impact). Thermal cycling causes stresses that would tend to propagate cracks through a sheet of glass. Some approaches to mitigate this problem are to use foamed glass instead of sheet glass, to design the collector as a faceted dish so that failure of one facet would not put the entire dish out of commission, and to attach the glass surface to another material that would support it (e.g., concrete).

*Fabrication Techniques.* Several techniques and conceptual design approaches were presented for producing concentrators from lunar materials (see Figure 2.2). A consensus was that molding techniques were preferred to free-forming techniques to reduce the risks in the production process. Several methods, including blow molding, spin molding, injection molding, stamping, and gravity sagging of a sheet into a mold, were determined to be applicable to glass production. Gravity sagging has the disadvantage of requiring production of glass sheet first. Spray-up on a male mold is the preferred technique for concrete collector production. Spin molding of concrete is not likely to be successful, because the concrete will have minimum water and will therefore be quite stiff. Material to be sintered could be placed onto a male mold, then pressed and sintered in place.

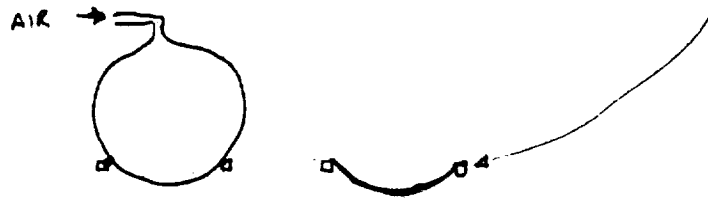
Use of solar energy as a heat source is attractive because of its availability and ability to be directed where desired by simple reflectors. The vacuum atmosphere makes heat loss reduction simple, since only radiative heat transfer is possible and, therefore, layers of thin foils will work as excellent thermal insulation.

*Conceptual Designs.* As mentioned above, free-forming of concentrators was felt to be more risky, so molded methods were preferred. Based upon the designs that were discussed at the meeting, the following are proposed as baseline designs to be examined initially:

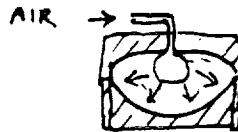
- Foam glass over male mold. The approach is to form a glass foam that can be poured/draped over a mold. As the front surface contacts the mold, the foam will coalesce to form a solid glass surface on which the reflective aluminum

## Parabolic Dishes

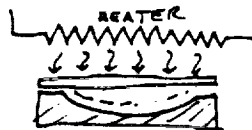
Blow-mold glass sheet into a spherical shape like a soap bubble; gravity sagging at the bottom would make it more nearly parabolic; extrude glass beams for the edge support ring.



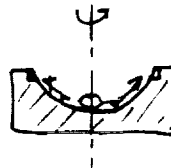
Blow-mold glass sheet into parabolic mold.



Gravity-sag glass sheet into mold.



Spin molding: rotating mold in which a thin layer of glass is melted as it rotates. When the glass cools, it takes on a perfect parabolic shape.



Concrete sprayed over parabolic mold, with glass fiber or iron fiber reinforcement; excess water removed by vacuum pumping and condensation; front surface coated with thin glass and aluminum to form reflective surface.



Squirt liquid glass into the air; the liquid will follow a parabolic path, solidifying as it goes, to form parabolic shapes. A single nozzle could produce parabolic ribs, a slotted distributor could make parabolic trough shapes, or a central distributor (like a sprinkler head) could produce a parabolic dish shape.

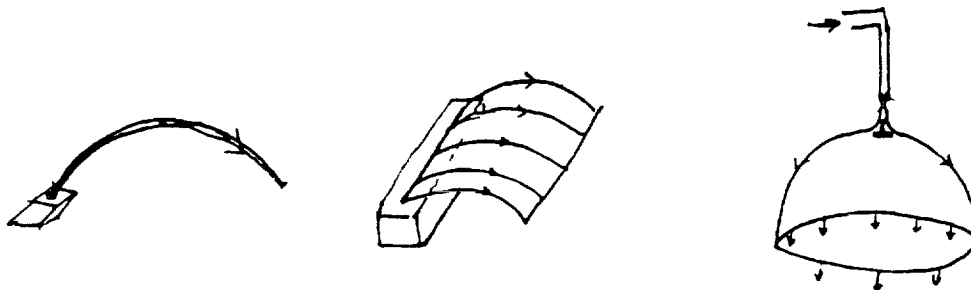


Figure 2.2 Solar collector manufacturing processes.

Figure 2.2 (Continued).

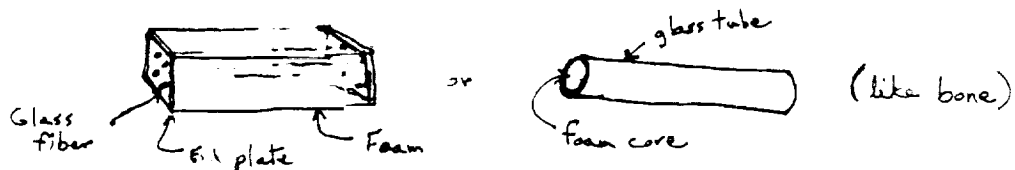
## Heliostats

Concrete poured into mold or sprayed over forms to make a ring; iron or steel foil, or very thin glass, for membrane. These heliostats would have to be unfocused, which would mean small sizes, or else the membranes would have to be self-supporting.

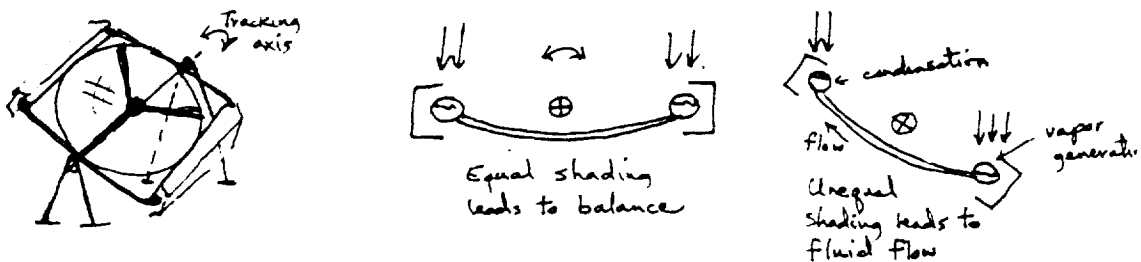


## Support Structures

Glass beams, with glass foam core for compressive loads and glass fibers for tensile loads.



Zomeworks-type passive trackers, based upon liquid-vapor balance system. This requires the system be supported very near the CG, and that an appropriate liquid be chosen.



## Miscellaneous

Sputtered aluminum first-surface mirror surface on glass substrates. The aluminum will oxidize slightly on the surface due to impingement of oxygen ions from the solar wind. This oxide layer will eliminate the dip in reflectance at about 880 nm that is present for a pure aluminum reflective surface, yielding an excellent reflector.



- layer can be deposited. The back of the dish will remain foam, for structural support and for protection against micrometeorites.
- Concrete applied over male mold. After molding, the concrete shell will be inverted and a thin glass layer applied, possibly by spin-molding. Finally, a reflective layer of aluminum will be applied to the glass surface.
- Iron-ore concentrator formed on male mold by sintering.
- Glass-glass composite. High-temperature fibers will be laid out on a mold, and low-temperature binder glass will be melted and forced to flow onto the mold to bind the fibers together, and form a composite.
- Heliostat ring of concrete, glass-glass composite, or foam glass-cored glass tube, with thin metal or microsheet glass membranes. Focusing via electrostatic forces (see below).
- Multi-faceted dish structure with foam-glass/glass beam construction to support mirror facets.

More designs can be added along the way if we come up with improvements.

*Miscellaneous.* Use of static electricity to focus heliostats was proposed. By placing opposite charges on the front and rear membranes, the attractive force between them will cause the membranes to deform to a shape approximating a parabola. This approach has been used in some satellite systems. An advantage over pressure-focusing is that pinholes due to micrometeorites will not affect the focusing system.

Due to the lack of wind loads, a very simple tracking device for parabolic dishes may be possible. A design similar to the passive tracker sold by Zomeworks for terrestrial photovoltaic systems might be appropriate. This tracker relies on a mechanical balance between two partially shaded accumulators that are partially filled with liquid. If the collector gets off-track, one of the accumulators becomes more exposed to the sun, increasing the vapor pressure in the accumulator and forcing more fluid to the other accumulator. The shift in the system's center of gravity causes the collector to rotate back to its proper tracking position. Since the lunar rotation axis is very close to perpendicular to the ecliptic, no seasonal adjustment for declination would be necessary, and a very simple polar mount would be sufficient.

*Testing.* It may be possible to simulate foam glass fabrication techniques at room temperature, using a standard polyurethane foam or an adhesive/glass microsphere mixture. As soon as we identify materials that duplicate as well as possible the lunar materials, we can begin some fabrication tests.

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